Stabilization and Upgrading Old Transportation Tunnels

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Abstract

Clearance improvement and rehabilitation of old tunnels can be a significant challenge. The stability of the lining, the condition of the ground behind the lining and the backfill behind the lining are often difficult to investigate. Removing the old lining and supporting the surrounding ground poses unique problems. The investigations and construction of repairs must often be conducted during short construction windows so that the tunnel can remain open for the remainder of the day. Consequently, flexible, innovative approaches are required for exploration, design, and construction of these projects.

Introduction

As our infrastructure has aged and our need for better transportation corridors has increased, many old tunnels have needed to be upgraded. The upgrading has included stabilizing tunnels that have deteriorated, increasing the clearance for larger trains or more traffic lanes, and providing connections between adjacent tunnels for greater safety or greater traffic flexibility.

Upgrading old tunnels is often more challenging than driving new tunnels. Many existing tunnels, especially railroad tunnels, are more than 100 years old and have no as-built design drawings or construction records. The attention to maintenance has usually varied over the life of the tunnels, and in some cases, has been discontinued entirely. There are many possible effects of aging, most of which can be accelerated by discontinuous maintenance. In some cases, the methods of maintenance actually damaged older structures.

It is often impractical or very expensive to increase the clearance in soil tunnels, except by lowering the invert. In soil tunnels, upgrades are, therefore, usually limited to supplementing or strengthening the existing lining, which usually reduces the clearance. Most recent tunnel upgrade projects have been in rock tunnels and this paper focuses on rock tunnel upgrades.

<u>Common Construction Practices in Old Tunnels</u>

There are no "typical" ground conditions or "typical" construction practices in old tunnels. Every tunnel is different and a wide range of construction practices was adopted. However, there are a number of common procedures that were used to construct rock tunnels before the modern "active tunnel support method" (particularly rockbolts, shotcrete and lattice girders) became standard practice, 20 to 40 years ago. The common procedures typically included:

- The use of drill-and-blast excavation;

- The installation of minimal rock support during tunnel excavation, except where immanently unsafe or unstable ground conditions were encountered;
- Construction of a free-standing, structural lining where the tunnel engineers thought it was required. The lining types included timber, brick, masonry, reinforced and unreinforced concrete, and steel; and
- Construction of aesthetically designed portal structures.

In some major cities different construction practices were used at different times so it is often possible to know the age of the tunnel by studying the construction materials, and vice versa. However, for many tunnels, neither the construction date nor certain aspects of construction and support methods are known.

Generally, where the tunnels are bald, or unsupported, the rock has remained stable over time. The linings, however, have deteriorated in many instances. The linings were usually constructed as free standing structures, leaving voids behind the lining. These voids were occasionally backpacked with shot rock, soil materials, or wood, but were often left open. Where voids or compressible materials were left behind lining structures, the excavation often relaxed and failed progressively upward, or stoped. In some cases, the weight of loose rock on the liners caused damage or failure of the lining. In other cases, linings were strong enough to support the added weight, but modifications to the lining may result in damage or failure.

Free-standing linings constructed over fifty years ago are usually unreinforced. These structures often do not meet modern seismic criteria and would collapse during earthquake shaking, even though rock tunnels generally behave well during earthquakes.

Portals are another element of tunnels that often deteriorate over time. The structural material and the cut slopes above portals often weather or loosen due to exposure to water and/or ice.

Issues and Constraints in Tunnel Upgrading:

The investigations and construction for tunnel improvement projects are often greatly complicated by the necessity to conduct the work under "live" conditions, where work is allowed only during limited intervals each day, and the tunnel must be returned to service in a stable condition at the end of each work period. In many cases, contracts stipulate the assessment of penalties to the contractor for returning the tunnel to service later than the specified time. Where commuter traffic is involved, these penalties are sometimes tens of thousands of dollars per minute.

Some tunnels have had a degree of repair installed over the years. These repairs were generally in the form of passive restraint systems such as installation of timbers, concrete linings, or a thin skin of gunite. These repairs, often effected as emergency measures, now can contribute to problems as they themselves begin to fail.

An additional concern can be the presence of portal or other structures that have been declared historically significant. Special care may be required to preserve these structures, and certain types of clearance improvement and ground support may be required by historic preservation organizations. In some cases, the historic structures may need to be taken down and reconstructed with the same materials.

For rehabilitation or clearance improvement of tunnels, which will be used for motor vehicles or mass transit, there is little tolerance for rockfall, uncontrolled drainage, or ice buildup. In most cases, such projects must be finished with full lining systems and enclosed drainage. Where tunnel rehabilitation or clearance improvements are being conducted strictly for freight railroad use, a greater degree of tolerance to minor rockfalls usually aids in effecting a more economical solution for final ground support. In some of these tunnels, rockfalls of less than three cubic feet are considered to be of only minor concern.

In some instances, it is possible to lower the roadway or track bed to provide additional tunnel clearance. However, this usually requires the tunnel to be taken out of service for many weeks. In many instances, the approach grades of bridges near the portals cannot be modified to accommodate lowering the invert of the tunnel.

Some Case Histories

The following sections describe some recent tunnel stabilization and upgrade projects. They include stabilization of a 120-year-old tunnel for use as a utility corridor, two rail tunnel clearance improvement and stabilization projects, and construction of crossover tunnels between existing transit tunnels.

Little Tunnel, Tennessee

As part of the Cumberland Gap Highway Tunnel Construction Project, the National Park Service needed to stabilize a 120-year old, disused railroad tunnel (called "Little Tunnel") so that it could be safely used for water, sewer and fiber optics lines.

There are two ground types in the tunnel. The western half of "Little Tunnel" was constructed through poor quality shale. This had been lined with a brick masonry arch, which was in excellent condition. By contrast, the eastern half of the tunnel had been constructed in good quality limestone, but had been lined with timber arches and wooden lagging. The wooden lining and timbers were in varying states of decay, with some areas sound and others completely rotten. Rock above the lining had stoped up to form a stable arch, but the relaxed rock was applying a significant loading to the timber arches in some locations, as shown in the upper part of Figure 1.

To stabilize the tunnel for utilities, it was necessary to remove the worst timber arches, support the newly exposed rock in the tunnel crown with rockbolts and shotcrete, and strengthen other marginally stable timber arches, as shown in the lower part of Figure 1.

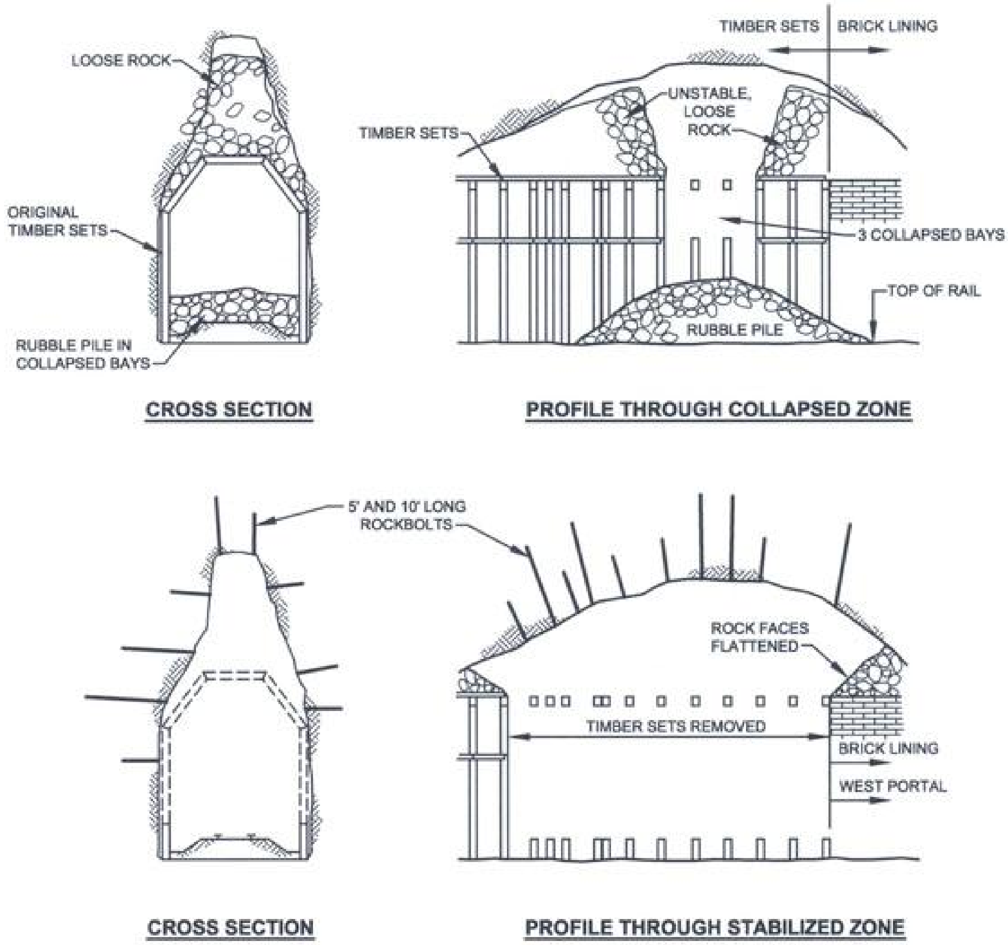


Figure 1 – Little Tunnel Stabilization

<u>Rockport Tunnel, Pennsylvania</u>

As part of the clearance improvement of Conrail's Philadelphia to Buffalo line, Rockport Tunnel required both vertical and horizontal clearance improvements. Vertical clearance was required for passage of double stacked container cars, while horizontal clearance was required to allow transport of large heat exchange vessels though the tunnel, as shown in Figure 2.

The 110-year-old tunnel was largely unlined except four portal structures and two lined sections in the northern half of the tunnel. All lining was comprised of stone masonry blocks. The tunnel experience severe seepage and ice buildup.

The exploration and clearance improvement work were to be conducted under "live" track conditions, with 8-hour work windows. An exploration program was conducted consisting of geologic mapping of the tunnel and surrounding outcrops, survey measurements of existing clearances, evaluation of existing linings and portal structures, and use of a jackleg drill and borehole camera, operated from a rail-mounted truck, to evaluate conditions behind the lined portions of the tunnel.

The survey and mapping indicated that the two inner sections of lining provided ample clearance but minor repairs were required to the one section of the lining due to undercutting of the masonry foundation during ditch clearing operations. Clearance improvements were found to be required in several unlined areas of the tunnel, and at both portal structures.

The sandstone bedrock in the tunnel was generally of very good quality. The shape of the tunnel was generally structurally controlled by bedding planes, jointing, and minor faults. Rock was too hard to permit excavation by roadheader. Therefore, drill and blast excavation was used for the clearance improvement. Rock support was provided by spot installation of resin-grouted rockbolts. The contractor elected to blast directly into air dump rail cars, which were widened by installation of steel "wings." Following clearance improvement and stabilization, Ethafoam insulation was attached to the walls in seepage areas to eliminate ice buildup during winter. Typical clearance improvement and rock stabilization in Rockport Tunnel are shown in Figures 2.

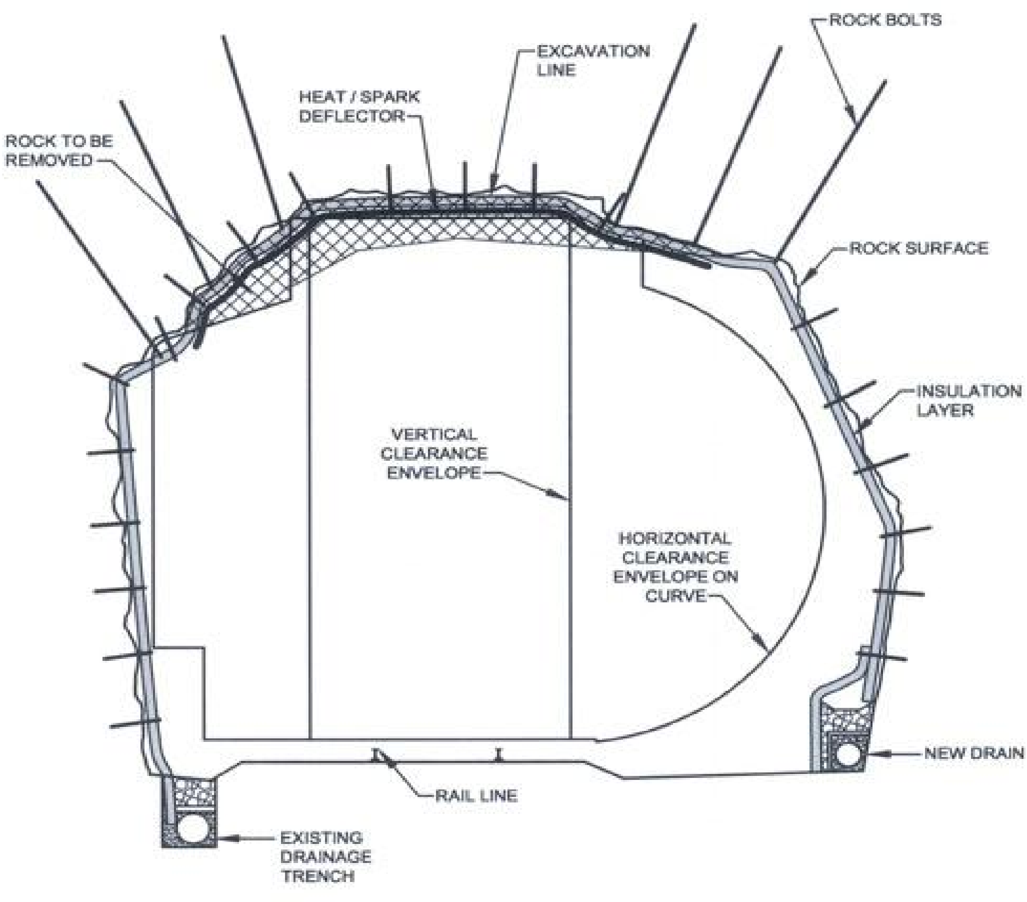


Figure 2- Rockport Tunnel Typical Clearance Improvement & Stabilization

Whitehaven Tunnel, Pennsylvania

Clearance improvement of White Haven Tunnel was conducted during the same project, which included Rockport Tunnel. Similar exploration methods and work windows were employed.

The approximately 130-year-old Whitehaven tunnel was constructed in sandstones and siltstones of varying quality, and was unlined except for the north portal area. Deterioration of the tunnel lining was evident near the portal, where previous repairs using gunite had been unsuccessful and were failing. The outside face and wing walls of the north portal structure consisted of hand-cut stone masonry, and were considered historically significant. Consequently, visual impacts to this portal structure had to be minimized. The south portal was entirely unsupported and the stability was threatened to slabbing of rock above the portal face. Ice buildup problems were significant, particularly in the vicinity of two vertical shafts that intersected the tunnel. Minor rockfalls in areas of weaker rock in the southern portion of the tunnel could only have been prevented by lining a significant portion of the tunnel. Because the rail line is used strictly for freight, Conrail decided that small rockfalls could be tolerated.

Vertical clearance improvements of up to three feet were required throughout much of the tunnel, including the south portal. Minor clearance improvements were also required in the north portal.

Initially, clearance improvement in unlined areas of the tunnel was attempted using a roadheader. However, the roadheader could not be adequately supported on a rail car, so the cutting rate was very slow. In addition, the roadheader used did not have sufficient range of side-to-side motion, resulting in the need to blast narrow slashes beside the roadheader cut. For these reasons, the remaining excavation was done using drill and blast methods similar to those used at Rockport Tunnel. Support was provide by pattern resin grouted rockbolts installed in the haunches of the newly excavated notches, with strategically placed rock bolting

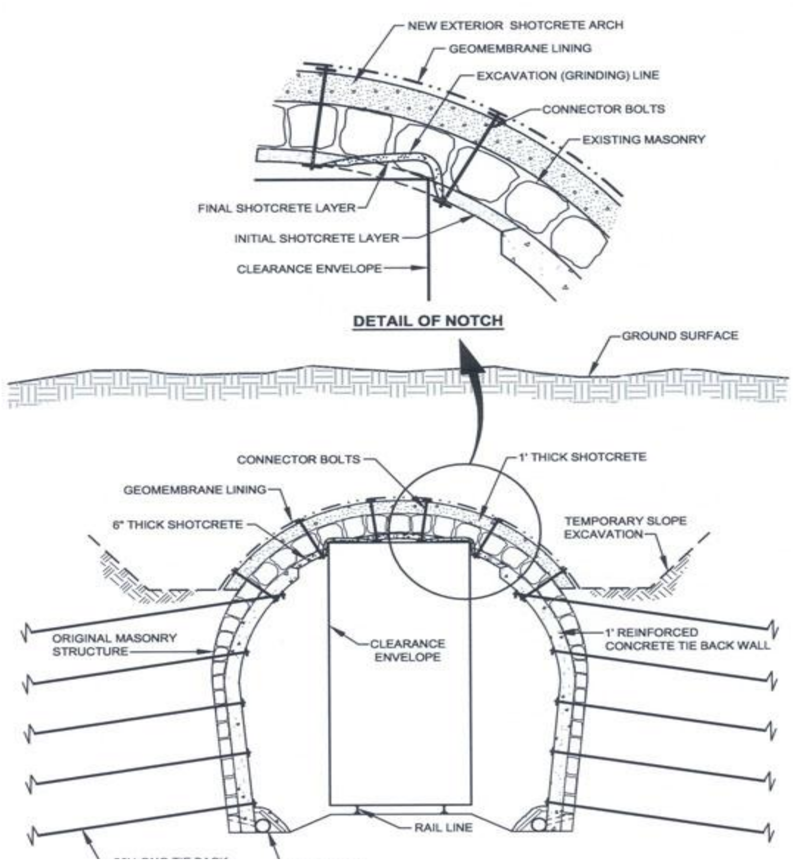


Figure 3 – White Haven Tunnel Clearance Improvement at Portal

in the crown and shotcrete installation where necessary.

Much of the deterioration of the north portal structure appeared to be due to seepage and ice jacking. It was necessary to support the north portal structure prior to notching for clearance improvement. Support and rehabilitation of the north portal are shown in Figure 3. The procedures used were:

1. Shotcreting the inside of the tunnel arch;
2. Installation of resin grouted rockbolts in the tunnel crown where bedrock was present;
3. Construction of -reinforced shotcrete walls in the bulged area of the side walls;
4. Coring through the new walls and the masonry lining and installing cement grouted ground anchors;
5. Carefully excavating soil slopes above the portal to expose the last 30 feet of masonry lining and cleaning the exposed surface with a blowpipe;
6. Installation of French drains from the outside haunches of the tunnel, around the portal;
7. Shotcreting the outside of the tunnel arch;
8. Installation of bolts through the worst portion of the masonry, which was discovered to have been the original portal location;
9. Installing a PVC liner over the arch to prevent inflows; and
10. Replacing, compacting, grading and seeding the cover soils over the portal structure.

After the masonry arch had been strengthened, clearance improvement could commence. The vertical clearance envelope required a small notch to be cut in the masonry on each side of the crown, as shown in Figure 3. Several methods of accomplishing this cut were examined, including saw cutting and grinding. Because vibrations had to be kept to a minimum, a system of saw cutting was selected. Notching was conducted in four-foot lengths, using alternate spacing (four feet cut, skip four feet, cut the following interval, and so on). A saw guide track was installed along the desired notching area, parallel to the tunnel alignment. A concrete saw mounted on the guide track was used to make a shallow cut, about one inch deeper than required for clearance, along the guide track. The track was then offset two inches, and the cut duplicated. This procedure was repeated until saw cuts were completed over the full width of the desired notch. A hydraulic splitter was then used to break out the stone between the notches. The notch was then cleaned and a thin layer (1 inch) of fiber-reinforced shotcrete was installed to knit the masonry together within the notch. After alternating sections were notched and shotcreted, the guide track was re-set, and the intervening sections notched. In this manner, clearance improvement was conducted without significantly weakening the masonry arch and with minimal aesthetic impact on the historically significant portal face.

As at Rockport Tunnel, ice buildup was remedied by installing Ethafoam insulation installed conformably to the tunnel walls with galvanized pins, and tied to an enclosed, insulated drainage system. The spark deflection sheets of soft aluminum were installed in the crown of the tunnel to protect the Ethafoam from the train exhaust.

Exchange Place, New Jersey

Following the tragic events of September 11, 2001, the Port Authority of NY & NJ (PANYNJ) set in motion plans to re-establish commuter rail service to its former Port Authority Trans-Hudson (PATH) World Trade Center (WTC) Station. These plans involved constructing a new, temporary WTC Station, dewatering and rehabilitating PATH's twin Hudson River tunnels (90 to 100 years old) and upgrading the Exchange Place Station to accommodate "terminal" rail services.

Design and construction of the Exchange Place Improvements Project required the development of seven new crossover tunnels upwards of 18 m (60 ft) in width, as shown in Figures 4, 5 and 6. This project was exposed to numerous contractual, technical and management challenges, which impacted the project's overall critical path.

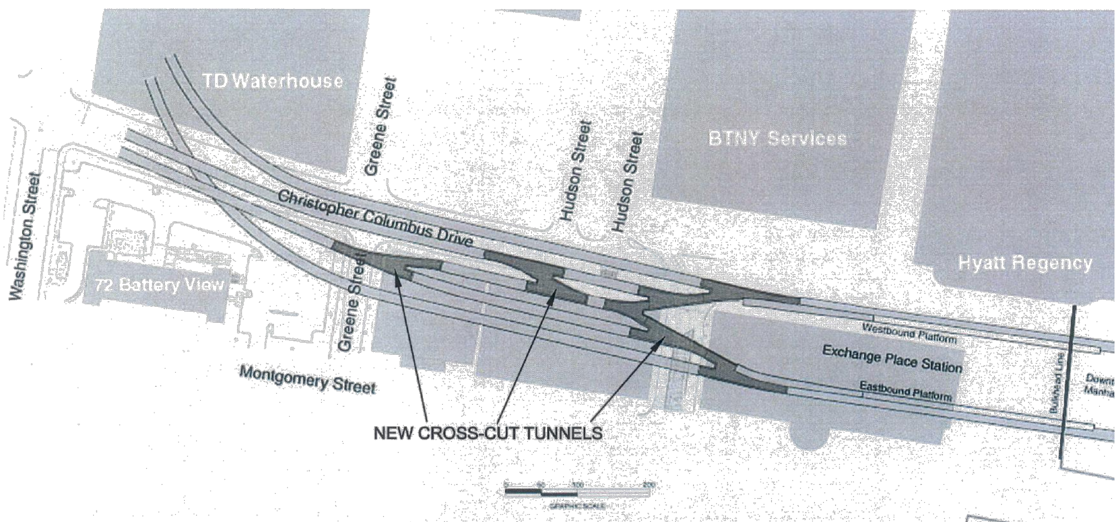


Figure 4 – New Cross-Cut Tunnels

At the project's onset, it was envisioned that tunnel excavation activities would be undertaken and completed using controlled rock blasting techniques. However, the Contractor was unable to adequately control excavated perimeters, which resulted in excessive rock over-breakage and schedule slippages. Therefore, alternate methods of rock excavation were

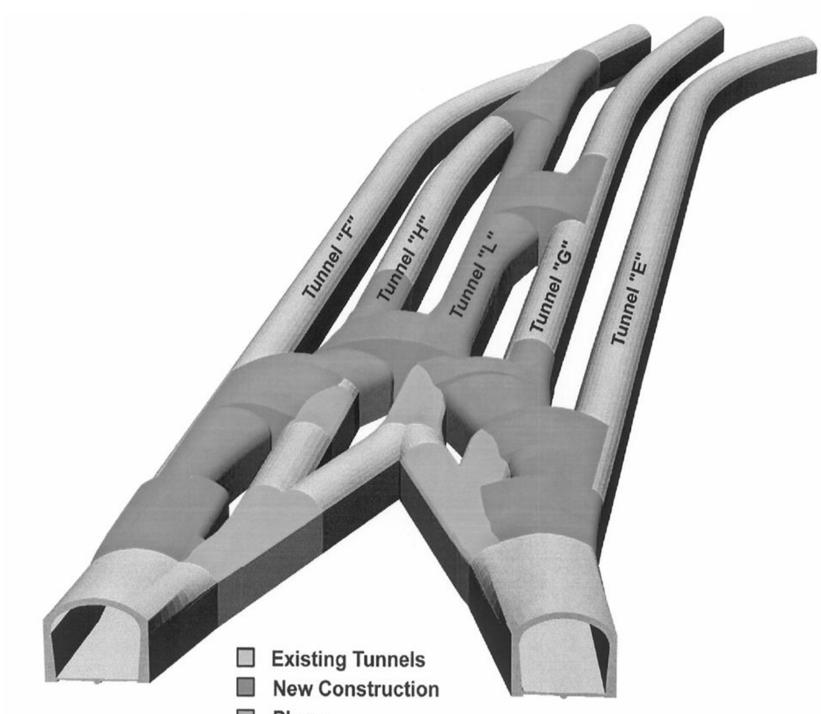


Figure 5 – Model of Underground Work

investigated, and roadheaders were used to minimize rock over-breakage and accelerate tunnel excavation activities, as shown in Photograph 1.

It should be noted that roadheaders had never been used to excavate the local Manhattan Schist, before consideration on this project, and the Contractor and other industry professionals familiar with the project expressed reservations and concerns that roadheaders might not be well suited to excavate the rock. However, testing indicated the compressive strengths of the rock only ranged from 27.6 to 34.5 MPa (4 to 5 ksi), which supported usage of roadheaders to excavate the rock.

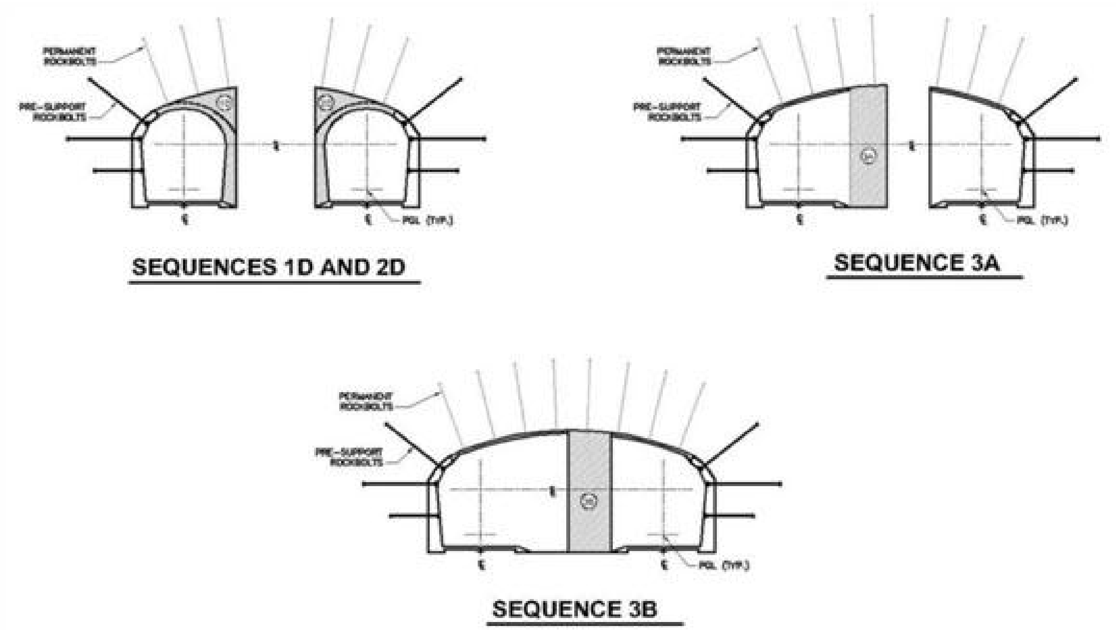
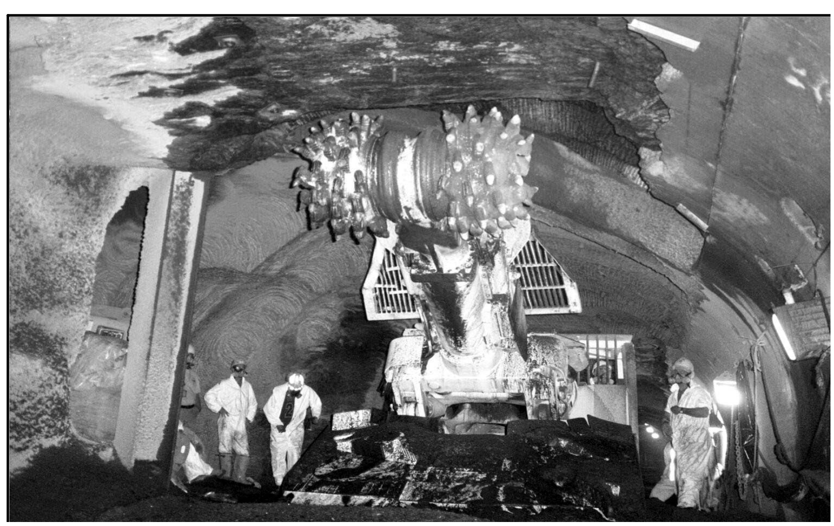


Figure 6 – Tunnel Excavation, Ground Support

Prior to start of tunnel excavation work, the Contractor installed pre-support rock bolts and contact grouted behind existing liners to strengthen linings to remain. Pre-support rock reinforcement consisted of galvanized, resin grouted rock bolts spaced at 1.5 m (5 ft) centers.

The project also included the use of a "single-pass" steel fiber reinforced shotcrete (SFRS) tunnel liner system. Nominal shotcrete thicknesses varied from 0.15 to 0.28 m (6 to 11 in), depending on excavated span lengths. In addition, SFRS linings were used in combination with steel lattice


Photograph 1. Roadheader Working in Tunnels

girders and rock bolts to provide the needed ground support. SFRS linings were constructed utilizing "wet-mix" techniques, and steel fibers were incorporated into the mix design to offset needs for welded wire fabric, which saved time during construction. In general, SFRS materials were delivered using drop pipes from street-to-tunnel levels, and applied using nozzlemen and assistants operating from aerial man-lift equipment.

On June 29, 2003, the Exchange Place Station re-opened to commuter service, and the new WTC Station re-opened before the end of 2003.

Concluding Remarks

Each tunnel enlargement or rehabilitation project presents unique challenges that require ingenuity, flexibility, and innovative solutions. A clear understanding of the owner's goals regarding scheduling, work conditions, budgetary concerns, intended end use, historical/aesthetic considerations, and level of acceptable risk is vital. "Boilerplate" types of approach cannot be applied to rehabilitation work on these historic tunnels. Successful rehabilitation work can only be accomplished using flexible designs and close cooperation between owner, designer, and contractor.